

where:

A= Pixel Area

d= Range (separation between the probe and TC camera face)

ϵ = Dielectric Constant of air

- 5 Table 1 shows the affect of probe distance on various parameters for probe distances below 6" with each row/column in series combination with 450 Ω , at a 100 MHz oscillator and voltage of 12V and 1.2V across the series combination with the oscillator voltage reduced to 1.2 volts at close range, e.g., 0.010468 in. (26 μ m), the signal is 1.126V.

- 10 Thus, probe distance can be ascertained using the relationship

$$V_{osc} = V(S) = \frac{I(S)}{G} R + \frac{I(S)}{SC}$$

$$\text{So, } C = \frac{I(S)}{S(V(S) - I(S)R)}$$

Since C is related to probe distance (d) from the capaciflector screen, $d = \frac{\epsilon A}{C}$.

Table I					
Range	C	$X_{c \max}$	I	Signal	Vosc
(in.)	(pF)	(k Ω)	(μ A)	(mV)	V
6	12	132.6	90.2	60	12
3	24	66.3	179.7	119.5	12
1.5	48	33.2	357.1	237.4	12
0.75	96	16.6	704.7	468.6	12
0.375	192	8.29	1,373	913.1	12
0.1875	384	4.14	2,612	1,737	12
0.09375	768	2.07	475.7	316.4	1.2
0.041875	1536	1.04	807	537.0	1.2
0.0209375	3072	0.518	1,240	824.4	1.2
0.01046875	6144	0.259	1,693	1,126	1.2
0.00523438	12,288	0.1295	2,071	1,377	1.2

Lateral probe movements may be determined by considering that reducing range and deriving current from the same pixel area (i.e., holding pixel area constant) provides the same response as holding the probe range constant and increasing the pixel area by the same factor. So, an increase in signal from an object at close range, for example at 0.010 in. (25mm) above $\frac{1}{2}$ pixel and moving in the X-Y plane to cover the entire pixel, provides the same response pixel as holding the probe, directly above the pixel at 0.020 in. (50mm) and moving it closer in the Z direction to 0.010 in. (25mm). From Table 1, above, it can be seen that at 0.010" the signal is 1.126V and 0.8244V at 0.020" for a signal difference of 0.3016V. Approximately the same signal change results from moving laterally in the X-Y plane at a probe height of 0.010" e.g., from covering half of a pixel to covering the entire pixel. So, for accurate positional location, preferably, sense circuits are sensitive enough to discriminate a 60mV signal difference. Further, typically, multiple pixels are affected by probe location and so statistical techniques may be

employed to improve probe resolution. Such signal discrimination circuits and techniques are well known in the art.

Figure 5 shows a plan view of an alternate embodiment 3-D interactive transparent capaciflector camera 160. In this TC camera embodiment, instead of finely spaced grids of thin silver wires, each of the two orthogonally placed layers includes row/columns of conductive glass plates 162 arranged over the screen. As in the above embodiment, there are two orthogonal layers of these plates or pixels, an X layer and a Y layer. The plates 162 (pixels) in each layer are arranged such that when the two layers are overlaid, alternate pixels in each row or in each column belong to alternate ones of the two layers. Each of the plates 162 is, preferably formed from a thin transparent layer of conductive glass, 0.001 inches (25 microns) thick, as described above for the shield layer of the first preferred embodiment. Each plate in this embodiment is 1/4" square (.62 centimeters by .62 centimeters). A plate connection row/column wire runs along the direction of the layer, i.e. in the X direction for the X layer and the Y direction for the Y layer, connecting plates for that layer together and to a sensor pad. A single oscillator 168 is shown interfaced with an array of high impedance operational amplifiers (op-amps) 166 each, of which, is configured as a voltage follower current source. The output of each voltage follower is connected to a single element of the sensor array, either a row, a column or the driven shield 163.

Figure 6 is blowup of area 164 in Figure 5, showing four adjacent pixels 170, 172, 174, 176. As is shown in Figure 6, horizontally running wires 178, 180 contact row pixels 170, 176 on the first (row) layer of pixels, respectively. Vertically running wires 182, 184 contact column pixels 174, 172 on a second (column) layer, respectively. As in the above preferred embodiment, these two pixel layers are formed above a shield layer (not shown), which is formed on the screen surface of a CRT (not shown).

The TC Camera 160 of this alternate embodiment is formed similarly to the above first embodiment. First, a shield layer is formed on the face of a CRT and a first dielectric layer is formed on the shield layer. Then, a first wire layer is formed, but with a single wire per row/column instead of 5 as in the preferred embodiment. A first pixel

layer is formed on the first wire layer. The flat square pixels 162 are formed by depositing a thin conductive glass layer as above and patterning using any well known patterning technique, e.g. a photolithographic pattern and etch. Each of the pixels 162 in this first layer is above and touches only one of the lines and is formed in equally-spaced rows/columns of alternating pixels and spaces, approximately, of equal size. Thus, each square pixel 162 is bonded to one of the equally-spaced, parallel, flat, electrically-conductive row/column wires located directly below it. A second dielectric layer is formed on the first pixel layer. Then, a second pixel layer is formed on the dielectric layer. The second pixel layer is formed identically to the first with pixels 162 being interleaved with the first, i.e., pixels of the second layer placed over spaces of the first and spaces of the second placed over pixels of the first. Next, a second wire layer is formed on the second pixel layer. The second wire grid is formed orthogonally to the first and, preferably, identical with the first, each wire passing over a single column/row, contacting pixels in the second pixel layer over which the wire passes directly. By arrangement of pixels and spaces both within each layer and between the two (2) layers of pixels, TC camera 160 is formed with its face fully covered by pixels 162, pixels 162 being equally and uniformly divided between rows and columns. Finally, the entire TC camera 160 surface is coated with a suitable tough and hard, insulating, fully-transparent coating above the second wire grid, approximately 0.005 in. (125 μ m) thick. This surface layer may act as a writing surface for a scribe-probe 102, so it must be a scratch resistant material.

Figure 7 shows another alternate embodiment TC camera 190 which has a basket weave type receptor field 192. In this embodiment a basket weave transparent capaciflector camera is constructed in much the same manner as the above first alternate embodiment and essentially operates in much the same manner.

Figure 8 shows another alternate embodiment TC camera 194 wherein the width of column pixels 196 is different than the width of row pixels 198. This embodiment operates much as the above embodiments except that the disparate sizes and arrangement

of column sensors and row sensors must be considered in signal analysis. The larger bottom pixels 196 compensate for blockage by the overlying top pixels 194.

Figure 9 shows yet another alternate embodiment TC Camera 200 wherein the row pixels 202 overlap each other in 2 layers each. This embodiment includes 2 layers of plate type row pixels 204 arranged from left to right and 2 layers of row pixels 206 are arranged from right to left, each row meeting in the center, but separated by a small gap 208. It is also apparent that in this embodiment, that the pixels 202 act as driven shields for each other, simultaneously sensing approaching objects. In this way, pixels 202 may be passed beneath each other without causing interference, acting as mutually driven shields with the upper pixel faces acting as a TC camera for an approaching object. With this embodiment, the effect of pixel rows and columns is achieved, even though the device is constructed physically, only, of either rows or columns.

Optionally, where precision is not a primary concern, the first and second wire layers may be omitted for the alternate embodiments of Figures 7-9. Table 2 shows the effect of eliminating the wire layers on signal, maintaining the oscillator voltage at 12V throughout. The difference in results between Table 1 and Table 2 can be understood with reference to U.S. Patent No. 5,166,679 entitled "Driven Shielding Capacitive Proximity Sensor" to Vranish et al., which is incorporated herein by reference.

Table II				
Range	C	$X_{c \max}$	I	Signal
(in.)	(pF)	(k Ω)	(μ A)	(mV)
6	12	132.6	63.4	63.4
3	24	66.3	97.6	97.6
1.5	48	33.2	133.7	133.7
0.75	96	16.6	163.9	163.9
0.375	192	8.29	185	185
0.1875	384	4.14	197	197
0.09375	768	2.07	205	205
0.041875	1536	1.04	208	208
0.0209375	3072	0.518	210	210

Figure 10 shows another alternate embodiment TC Camera 210 wherein column or row pixels are triangularly-shaped to form herring bone rows or columns. In this embodiment similar to overlapping pixel alternate embodiment of Figure 9, pixels are arranged only in rows (or columns) but are triangularly shaped to yield additional information and resolution about probe location. The triangular pixel pattern facilitates sensing lateral probe movement along one of the rows, the probe being detected by the row above and below the movement. It should also be noted that other periodic-type patterns (e.g., sinusoidal) can be substituted for the depicted herring bone arrangement.

Inclusion of the TC camera on a CRT results in an 3-D interactive display that may be used for a broad range of applications, such as for example, in support of a word processing computer program or a relatively sophisticated 3-D mechanical object design/analysis computer program (such as Pro-E for example). A word processing application example is provided in detail hereinbelow and is illustrative of the simplicity

and utility of such a 3-D interactive display for every day tasks. A 3-D mechanical object/analysis application example illustrates the power and capability range of such a 3-D interactive display.

Advantageously, the TC camera of the present invention enables real-time
5 interactive 3D communications between an operator and a computer. The computer receives 3-D locational input data, locating a probe with respect to the front of a display screen and maintains time based probe manipulation and location history. The computer interprets and integrates these 3D inputs in the context of a particular computer program. So, while the same 3-D capacitive image may be received for different computer
10 programs, the computer's displayed response depends upon the particular program, the computer interpreting the input differently for a word processing program differently than for a mechanical design drawing program or for an action video game. The operator interactively responds to changes on the display by moving the probe. In addition, although many current computer programs are enabled to adapt and reduce error using, for example, fuzzy logic or iteration techniques. The TC camera may receive multiple 3-
15 D inputs with the computer adjusting interactively, simultaneously reducing errors from both data processing ends.

Thus, for word processing for example, an operator directly interfaces with a computer screen performing the functions of a virtual mouse or, alternately, a touch pad.
20 A series of probe motions are recognized and executed by the computer. For example, a simple small check movement may establish cursor position, while a different small movement, e.g., a rubbing motion highlights a section for deletion. Similarly, entire sections of words, etc., can be high-lighted, either for deletion or for cut and paste. Documents may be signed interactively online. Also, technical sketches may be entered
25 by hand with dimensions placed on the drawings, with a computer converting the sketches to exact scale or to a solid model (e.g., in isometric) interactively rotating or moving the model, either by command or by virtual control. Similarly, math equations can be entered by hand with a computer converting the rough equations to any typed format of choice, thus facilitating and speeding writing technical papers and reports.

So, Figures 11A-B are flow diagrams showing the steps to effect a basic cursor movement while in a word processing program using the 3-D interactive display of the present invention. First in step 220, the TC camera detects the presence of a probe/finger. Then, in step 222 a processor, e.g. an embedded processor, separates the probe/finger image from the operator's hand, which is in the background and, computes the centroid of the probe/finger as defined by its X-Y-Z location. This information is passed to a display controller, e.g. a micro-processor, which interprets the information in step 224. Using a tapping motion, the operator can tap the probe or finger in step 2242 (analogous to a single click on a mouse) without necessarily touching the TC camera surface. In step 2244 the display controller responds to the tapping to compute a corresponding X-Y location for a cursive (including an offset to avoid requiring probe placement that might obstruct the operator's view) and display brightness and/or blinking in a field based on the centroid location. The display controller then displays the cursive on the screen, offset such that the cursive appears above the probe and is visible to the operator at all times. Initially, the cursive may blink, energetically, for a short period of time to draw attention to it and to announce its presence and its location to the operator. After the initial tap, in step 2246 lateral movement causes the cursive to follow the probe in real time in step 2248, highlighting words, pictures and equations it traverses. When the probe is removed, Z axis movement is detected in step 2250 and the cursive is halted in step 2252. Thus, in step 226, when it is determined that the probe has been removed from the transparent capaciflector camera field (i.e., its range changes abruptly), the cursive remains in place and blinks returning to step 220. When the probe is repositioned above or near the cursive, the cursive is reacquired in step 220 (as indicated, for example, by temporarily blinking energetically again) and the computer resumes following probe movement.

The operator may acquire a menu function in the same manner as the cursive is acquired, pointing slightly below the menu function to be acquired and tapping once. It should be noted that tapping is optional, and does not require touching the TC camera surface. The display may respond by changing the icon for the menu function to

acknowledge that the icon has been acquired. The operator then may tap the probe twice, again analogous to a mouse double-click, to open the menu.

Other typical word processing functions, such as highlighting, cutting, copying and pasting may be effected using a cursive to follow the probe, much in the same manner as a mouse is used for such operations. Once a section is highlighted, a normal keyboard entry may be used to cut, paste, delete or copy just as is currently done. Further, using the 3-D interactive display, several separate sections of a document may be highlighted simultaneously and selectively operated on simultaneously or independently with the keyboard. Thus, for the above described word processing program, the received 3-D image is a probe or finger centroid and the possible on screen reactions to 3-D image movements may range from establishing a cursive to highlighting a group of words, to opening an icon function, etc.

Virtual writing and drawing pads may be effected using a TC camera of the present invention and inherently, are more effective than current prior art such as temperature or pressure sensor array devices. With these prior art devices, a certain pressure must be maintained to sense properly. Elastic movement in a pressure pixel is very small, and the slightest variance in pressure may cause skips or other misinterpretations. By contrast, the transparent capaciflector camera of the present invention measures probe proximity, not pressure or temperature. Thus, movement is modeled and represented as an effective "virtual elastic movement" that may be set electronically, e.g. as an operator adjustment. For a word processing program, writing breaks occur when the writer deliberately lifts the probe away from the display, say on the order of at least 0.01 in., instead of when pressure varies a bit too much. Also, the high resolution of the TC camera is continuously providing determinable readings between pixels that, when combined with the 3-D data, provides detailed information about a particular task (e.g., writing/drawing) as well as affording superior fidelity for hand drawings and hand writing.

For a mechanical design program using the 3-D interactive display of the present invention to model a 3-D mechanical object using, for example Pro-E, the displayed 3-D

image may well include portions of the operator's thumb and those fingers nearest the screen. If the rendering of the operator's hand is shown approaching a 3-D display of a mechanical object, on screen reactions to hand movements may include allowing the operator to virtually manipulate the 3-D mechanical object using a "virtual touch/feel/grasp/rotation/translation." Thus, the display reflects appropriate object movement in response to operator hand movements, centering-up in a "virtual grasp" of the 3-D image. As the operator's hand rotates about any combination of the three spatial axes, the virtual grasp rotates, the 3-D hand image and manipulated object with the results being displayed on the screen. When the operator's hand opens, the 3-D hand image releases its virtual touch/grasp. The 3-D mechanical object is displayed remaining suspended in place and in position until virtual movement by a subsequent operator causes it to move. The operator may reposition his/her hand and "virtually regrasp" the object, turning it again in a ratchetting process until a desired view is obtained.

Thus, continuous, high resolution, 3-D imaging data from operator probe movements in the immediate vicinity of a computerized-screen are sensed by an invisible energy field directly over the face of the display screen. In effect the transparent 3-D camera and interactive display provides a 3-D image of an operator probe within 6 in. (150 mm) and closer to a computerized screen and, further, allows precise determination of operator probe point position and movement. The 3D interactive display inherently makes the interaction between probe position and the corresponding displayed computer response very precise, natural and user-friendly. By contrast, existing prior art manual input systems provide intermittent 2-D Data, e.g. from an invisible touch panel with an inelegantly large probe selecting much smaller pixels. In addition, existing 3D data entry devices (such as joysticks) are not transparent and so, cannot be placed directly over a display screen for a more integrated operating environment.

Advantageously, the present invention affords a 3-D, continuous, high-resolution imaging information input device wherein data/information is provided directly and interactively with a display face, thereby affording interaction between an operator and the display in a very direct, precise, natural and user-friendly way. The operator may

experience a "virtual touch/feel" that provides a direct and more natural 3-D virtual interface for object manipulation. Accordingly, this virtual touch may be provided on the fly and used to control other input devices, e.g., keyboards, joysticks, touch pads, writing/drawing pads, etc. Such a 3-D interactive display system is easily updated and upgraded, simply by changing the software and may be made independent of computer hardware and processors.

Virtually grasping and manipulating objects gives an operator a sense of the object, which is enhanced when the image responds to the operator's movements, giving the operator the illusion of grasping and manipulating the object itself, e.g. to view previously-hidden features. This virtual touch/feel feature of 3-D interactive display gives operators a positive, immediate and local (ultra user-friendly) sense of how operator actions are interpreted. So, for example, with an operator touching an image of a key on the 3-D interactive display, that key may blink responsively signaling the operator which key is selected. The screen can be curved to interact as a 3-D Shape such as the inside of a ball providing a 3-D Virtual Joystick.

Further, the 3D transparent capaciflective camera of the present invention may be disposed upon a liquid crystal diode (LCD) display for inclusion on a personal digital assistant (PDA) or a laptop computer. Optionally, for a laptop computer the keyboard/mouse/touch pad may be 3-D interactive displays or transparent capaciflector cameras. For such an arrangement, the near screen, i.e., the keyboard, may function as a 3-D interactive control panel in combination with a far screen which is the traditional display. Frequently, it may be advantageous to interface directly with a display image on the far screen, say to rotate or to move an object or to perform cut and paste for word processing. The keyboard can be reconfigured on the fly when a new application is started, e.g., to a phone key pad to make a cell phone call, to TV remote control or, to a remote control for a microwave or a garage door.

As can be seen from Figures 12A-F, the 3-D Interactive Display can be software-reconfigured into any number of input devices, especially keyboards, joy sticks, touch pads, writing/drawing pads, etc. Figure 12A shows the display 230 turned off or in its

deactivated state. The size, spacing, arrangement of function and labels of the soft keys are entirely at the operator's discretion. Thus, Figures 12B-C show the screen configured in two different interactive keyboard configurations 232, 234. Figure 12D is an example of the TC camera 236 configured for use as a virtual mouse. Figure 12E shows a TC camera 238 adapted for digital ink, for inputting handwritten information. Figure 12F shows a TC camera adaptation 240 as a keypad for a TV remote control, for example.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.